Satellite Dynamics About Eros

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The Near Earth Asteroid Rendezvous (NEAR) mission spacecraft will arrive at Asteroid 433 (Eros) in February, 1999. Following an initial period of characterization, the science phase of the mission will commence, and unprecedented information concerning an asteroid's shape, mass, density, composition and rotational dynamics will be sent to Earth for analysis. It will also mark the start of orbital operations about the most complex and irregular gravity field ever encountered in the history of space exploration. The severity of Eros' distortion from the usual spheroid bodies encountered in planetary exploration leads to fundamental differences in the orbital dynamics about it. Operations about Eros will also serve as an exciting test of orbit determination and prediction in an orbital environment which can be chaotic in some instances.

The current analysis assumes a shape, uniform density and rotational dynamics for Eros. In operations, the gravity field will be determined from Doppler tracking as coefficients of a spherical harmonic expansion and the rotational dynamics will be determined from optical pictures. For pre-encounter analysis the shape may either be specified as a constant density tri-axial ellipsoid (this shape contains the major non-spherical perturbations of Eros) of dimensions 40 x 14 x 14 km (based on ground observations), or as a constant density polyhedron containing 4202 vertex points (based on a supposed Eros shape). Either approach may use existing closed-form solutions for the gravity field or may use a harmonic expansion determined by integrating over the shape. The constant density of Eros is assumed to be $3.5\ g/cm^3$, although this is uncertain to a large extent. Eros has an observed rotation period of 5.27 hours, although it is not known if this is a uniform rotation or if there is significant precession and nutation. This analysis assumes a uniform rotation about the largest moment of inertia, although the analysis can be extended to the case where there is precession and nutation of Eros.

Given the assumed Eros rotational and gravitational model, the equations of motion of an orbiting spacecraft may be defined. It is useful to state them in both an inertial and a body-fixed frame (a uniformly rotating frame), as each formulation has its own benefits. In the inertial formulation it is possible to derive a theory of secular change in orbital elements, useful in planning and evaluating mission feasibility about such an asteroid. In the body-fixed frame it is possible to define a Jacobi integral, generate zero-velocity surfaces and compute periodic orbits all of which slid insight on orbit stability about Eros, and on the possible evolution of ejecta from Eros' surface (and hence possible distributions of co-orbitals).

Synchronous orbits (circular orbits in inertial space) and periodic orbits which repeat in the rotating body-fixed frame are computed. These computations are possible for an arbitrary gravitational field, and do not assume any special symmetry. The study of the stability of these stationary and periodic orbits sheds light on the general stability of orbital motion about Eros. It is found that all four synchronous orbits are unstable (in opposition to the usual planetary case where there are two stable and two unstable synchronous orbits). Additionally) direct orbits within ≈ 2 radii are unstable and tend to crash onto or escape from Eros within days. Conversely, almost all retrograde, equatorial periodic orbits are stable, even when within hundreds of meters from Eros' surface. This highlights the stability of retrograde orbits in general. Some notable exceptions to the above observations are also noted.

Finally, general orbital dynamics about Eros are discussed. Some simple formulae are given for the secular motion of the node and argument of periapsis. Conditions for a satellite orbit to escape from Eros are discussed, and some simple results derived. Finally, the chaotic nature of certain orbits about Eros are discussed, and the consequences for orbit prediction are investigated.